

# DØ Search for the Higgs Boson in Multijet Events

Alex Melnitchouk

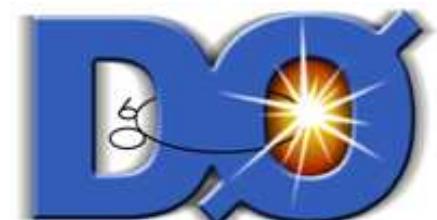
**University of Mississippi**

**For the DØ Collaboration**



PANIC 05

Santa Fe, NM, October 2005



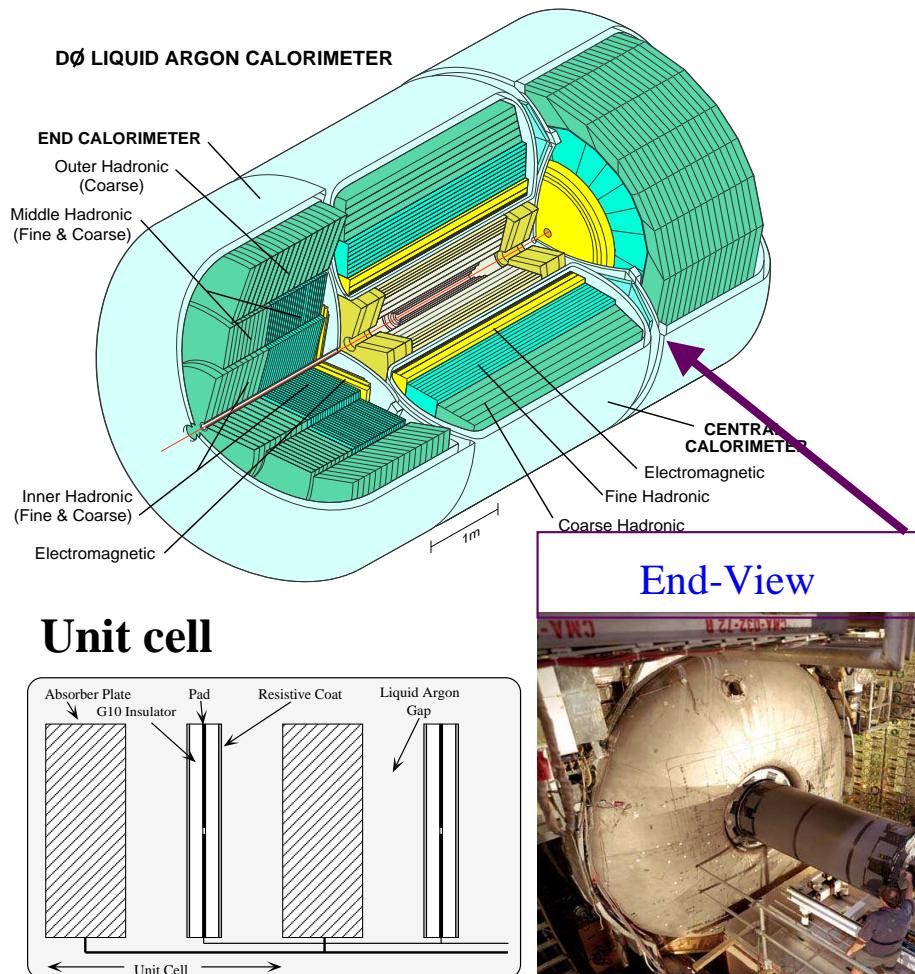
# Introduction

- Two analyses are presented in this talk:  
**ZH→vvbb** and **b(b)h→b(b)bb**
- **ZH→vvbb** : a DØ Search for the Standard Model Higgs
- **b(b)h→b(b)bb** : SUSY Higgs Search at DØ
- In both analyses final state contains b-jets

→ need good understanding of calorimeter response and b-tagging

# DØ Calorimeter and Tracking System

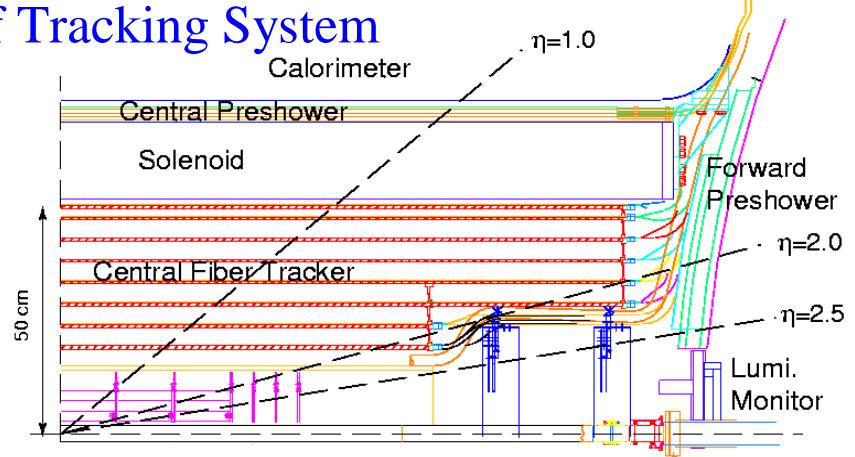
- Uranium/Liquid Argon Sampling Calorimeter
- Three modules:
  - central calorimeter (CC)
  - two end-cap calorimeters (EC)



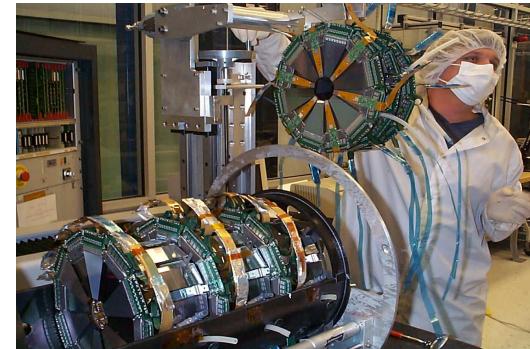
- Central Fiber and Silicon Microstrip Tracker



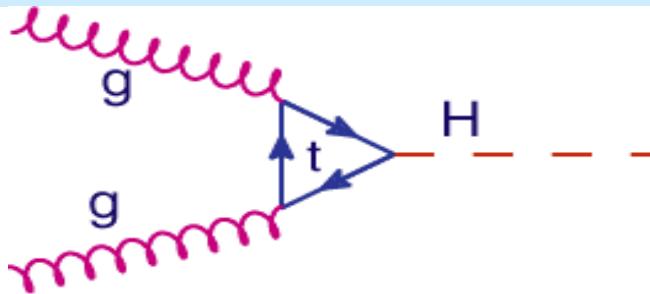
One-Quarter  $r$ - $z$  View  
of Tracking System



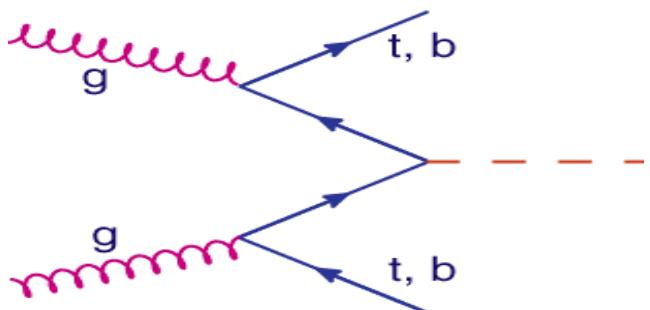
Silicon Microstrip Tracker



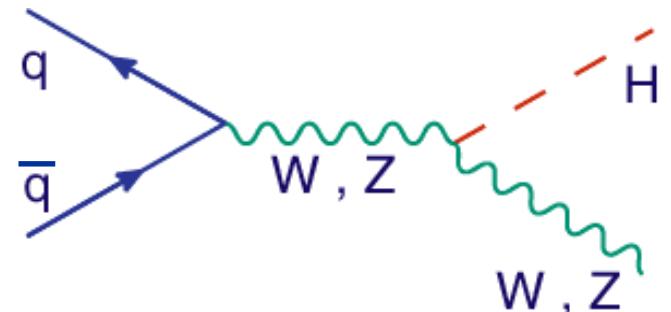
# SM Higgs boson production



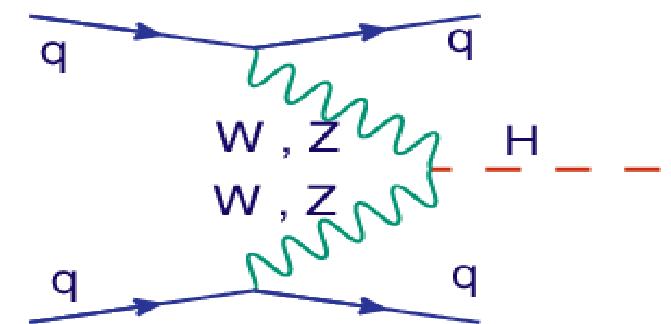
- gg fusion
  - Dominates at hadron machines
  - Usefulness depends on the Higgs decay channel



- In association with  $W, Z$  (higgsstrahlung)
  - Important at hadron colliders since can trigger on 0/1/2 high- $p_T$  leptons
- ttH and bbH associated production
  - High- $p_T$  lepton, top reconstruction, b-tag
  - Low rate at the Tevatron



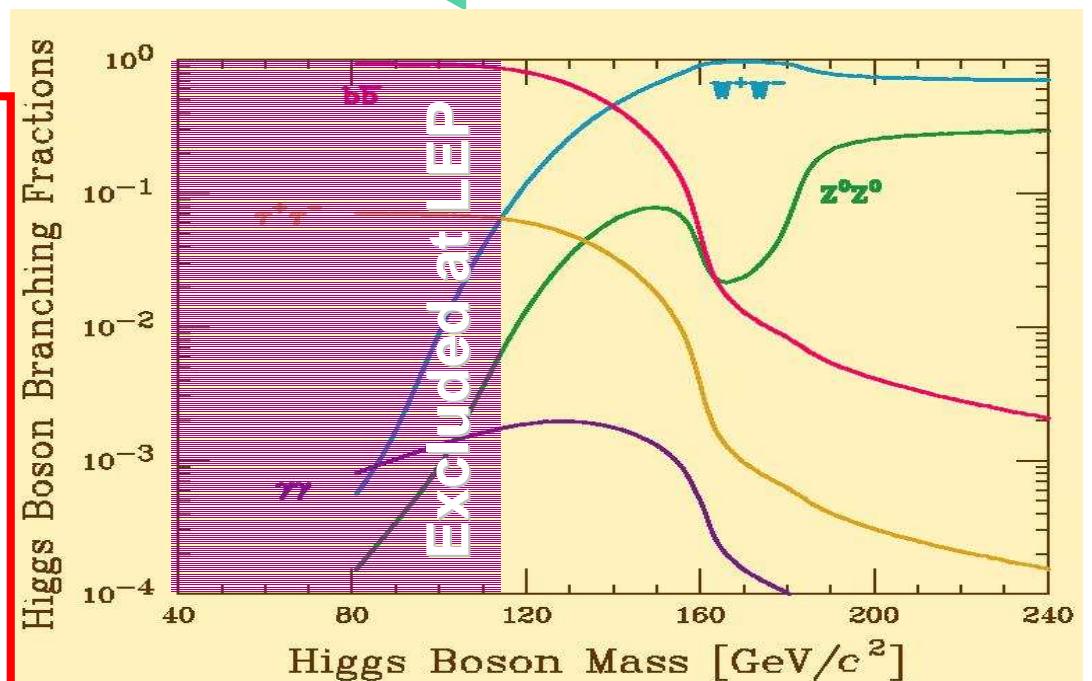
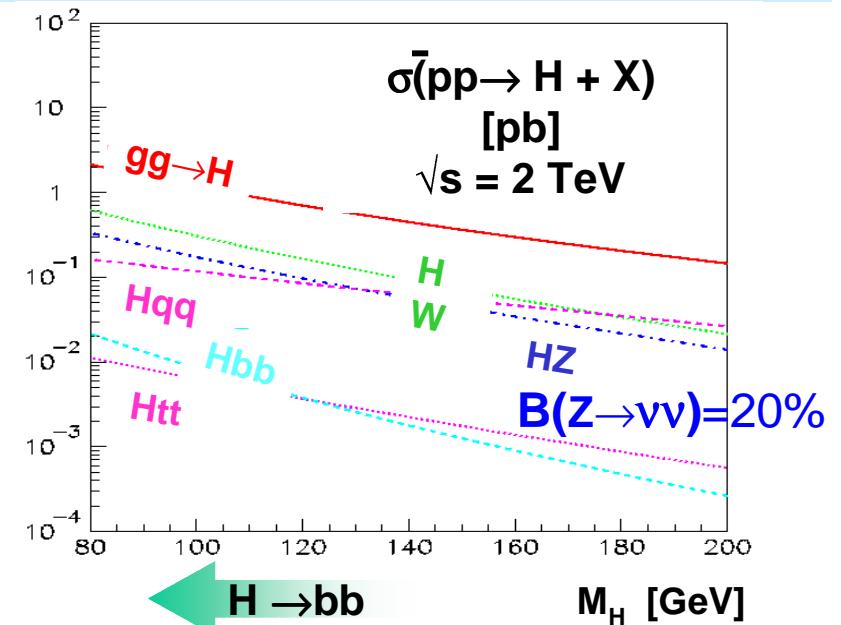
- Vector Boson Fusion
  - Two high- $p_T$  forward jets help to “tag” event
  - Important at LHC



# Low Mass Region Higgs Searches. Why $ZH \rightarrow vvbb$

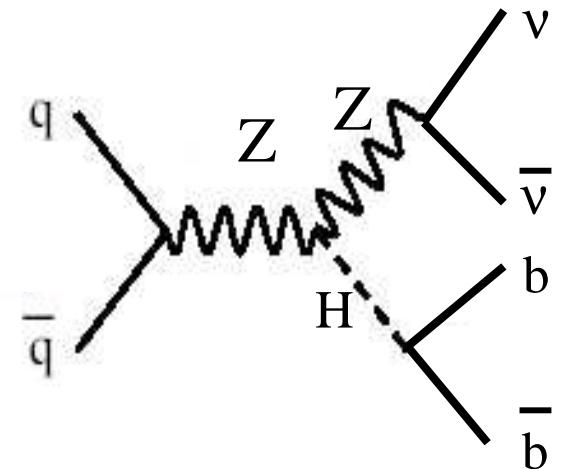
$M_H < 135 \text{ GeV}$ :  $H \rightarrow bb$

- Higgs produced in gluon fusion has too large QCD/bb background
- Search for  $(W/Z)H$  production where  $W/Z$  decay leptonically
  - $qq' \rightarrow W^* \rightarrow WH \rightarrow \ell vbb$ 
    - Bkgd:  $Wbb, WZ, tt, \text{single top}$
  - $qq \rightarrow Z^* \rightarrow ZH \rightarrow \ell^+\ell^-bb$ 
    - Bkgd:  $Zbb, ZZ, tt$
  - $qq \rightarrow Z^* \rightarrow ZH \rightarrow vvbb$ 
    - Bkgd:  $QCD, Zbb, ZZ, tt$
- Cross-Sectin x Branching Fraction  $\approx 0.01 \text{ pb}$   
(almost as large as  $qq' \rightarrow W^* \rightarrow WH \rightarrow \ell vbb$ )
- Tag b-jets
- Disentangle  $H \rightarrow bb$  peak in di-b-jet mass spectrum



# ZHà vvbb searches

- Missing  $E_T$  from Zà vv and 2 b jets from Hà bb
  - Large missing  $E_T > 25$  GeV
  - 2 acoplanar b-jets with  $E_T > 20$  GeV,  $|\eta| < 2.5$
- Backgrounds
  - “physics”
    - W+jets, Z+jets, top, ZZ and WZ
  - “instrumental”
    - QCD multijet events with mismeasured jets
      - Huge cross section & small acceptance
- Strategy
  - Trigger on events with large missing  $H_T$ 
    - $H_T$  defined as a vector sum of jets’  $E_T$
  - Estimate “instrumental” background from data
  - Search for an event excess in di-b-jet mass distribution

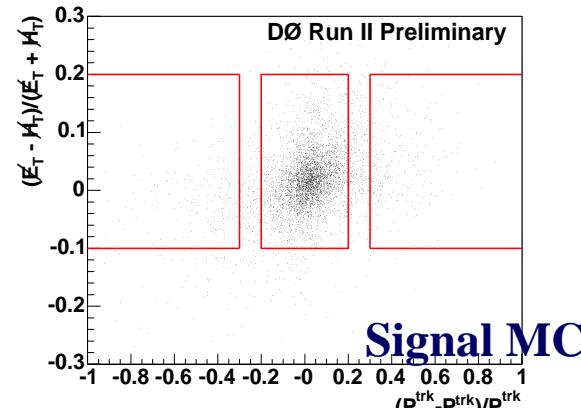


# More selection variables

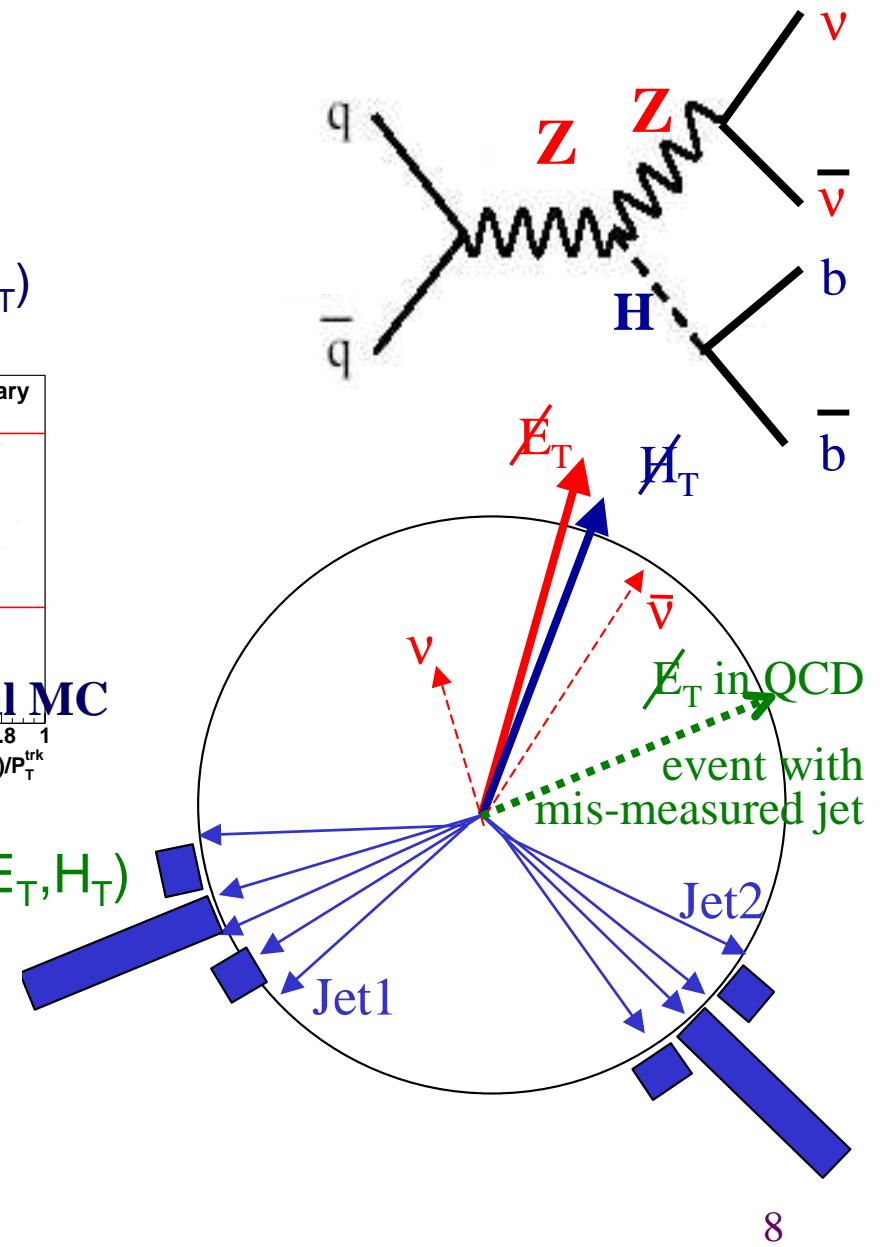
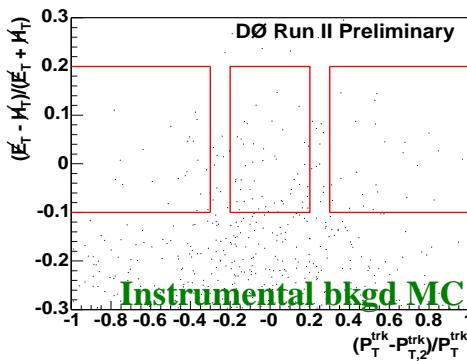
- Suppress “physics” background
    - In addition to missing  $E_T > 25$  GeV and two jets with  $E_T > 20$  GeV
    - Veto evts. with isolated tracks    $\beta$   reject leptons from W/Z
    - $H_T = \sum |p_T(\text{jets})| < 200$  GeV        $\beta$   for tt rejection
  - Reduce “instrumental” background
    - Jet acoplanarity  $\Delta\phi(\text{dijet}) < 165^\circ$
    - Various missing energy/momentun variables
      - $\cancel{E}_T$                           calculated using calorimeter cells
      - $\cancel{H}_T = -|\sum p_T(\text{jet})|$                   ... jets
      - $P_T^{\text{trk}} = -|\sum p_T(\text{trk})|$                   ... tracks
      - $P_{T,2}^{\text{trk}} = -|\sum p_T(\text{trk in dijet})|$  ... tracks in jets
  - Form various asymmetries
    - $\text{Asym}(\cancel{E}_T, \cancel{H}_T) = (\cancel{E}_T - \cancel{H}_T)/(\cancel{E}_T + \cancel{H}_T)$
    - $R_{\text{trk}} = |P_T^{\text{trk}} - P_{T,2}^{\text{trk}}|/P_T^{\text{trk}}$
- à In signal like events they all peak at  $\sim 0$  and are aligned

# Example: $E_T, H_T$ Asymmetry

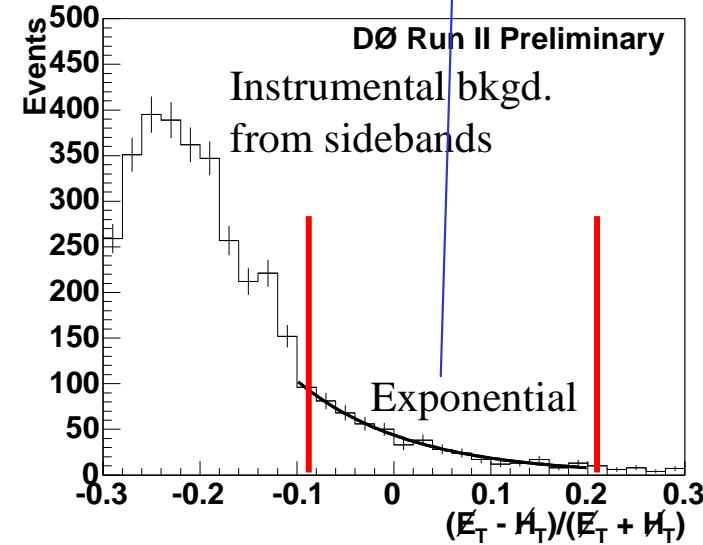
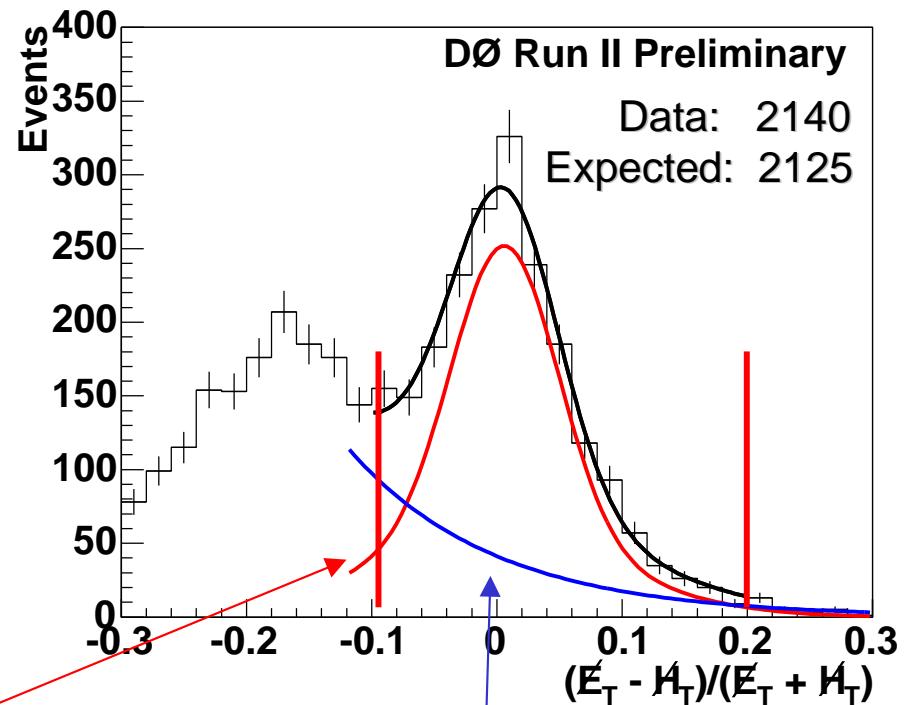
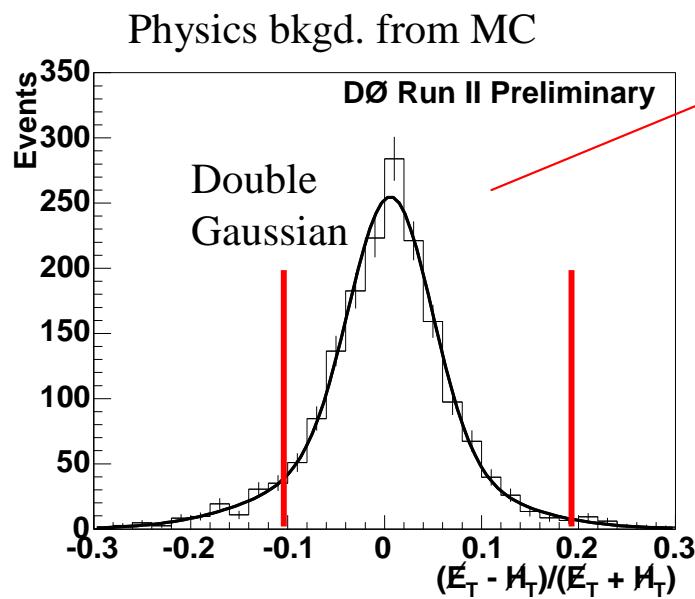
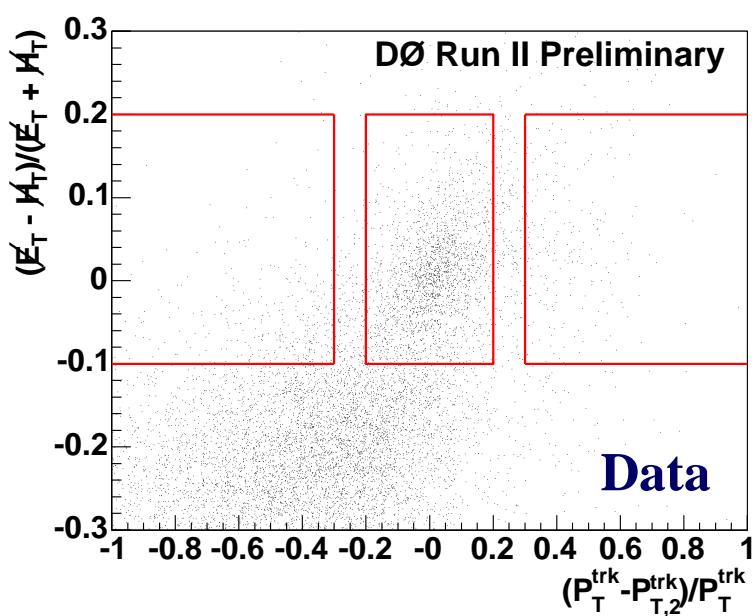
- In signal events there is  $P_T$  balance between Higgs and Z-boson  
 $\rightarrow P_T$  balance between  $vv$  and  $bb$   
 $\rightarrow \text{Asymmetry}(E_T, H_T) = (E_T - H_T)/(E_T + H_T)$   
peaks at 0



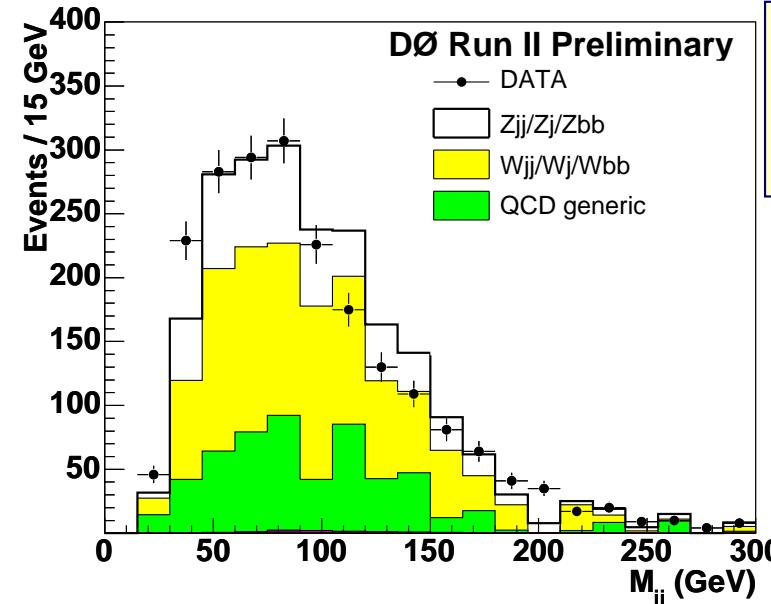
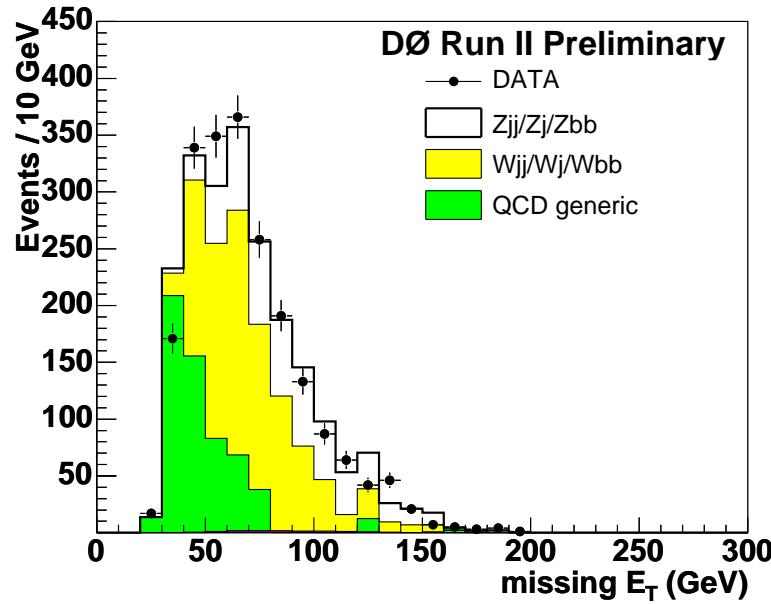
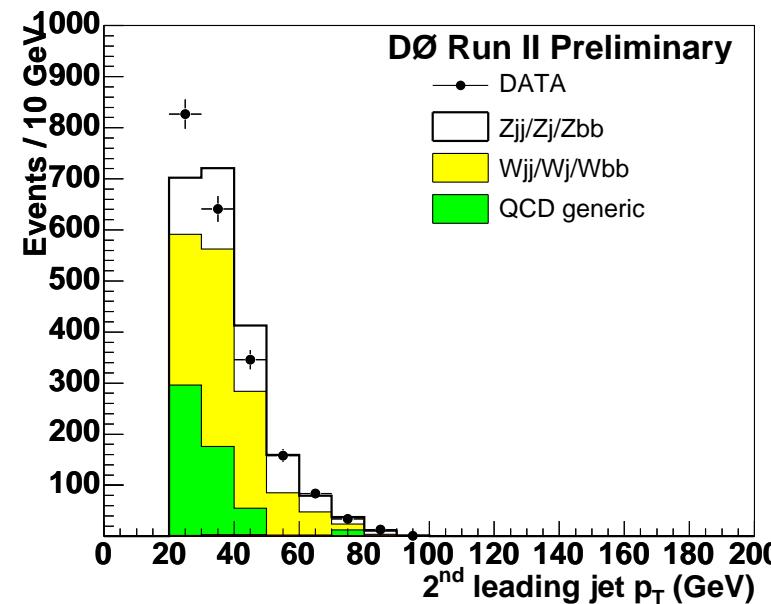
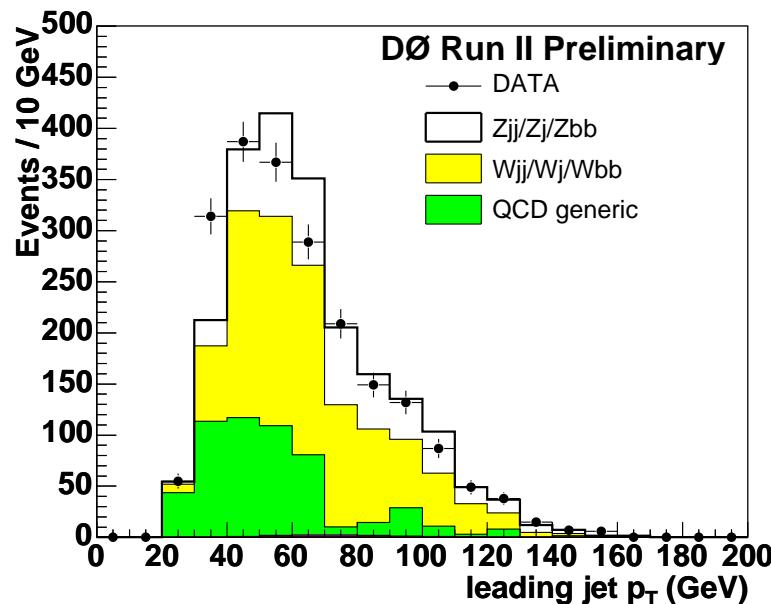
- Instrumental background (calorimeter mismeasurements of multijet events)  $\rightarrow$  Large Asymmetry( $E_T, H_T$ )



# Background Estimation

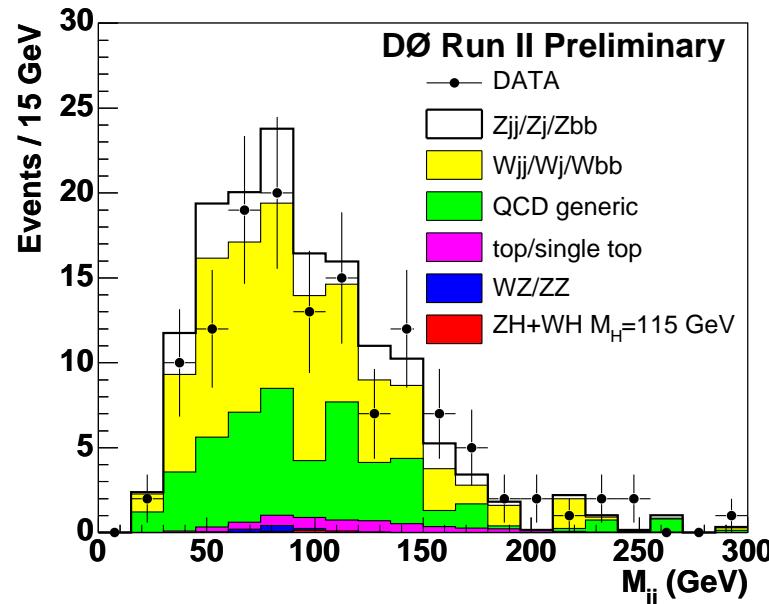
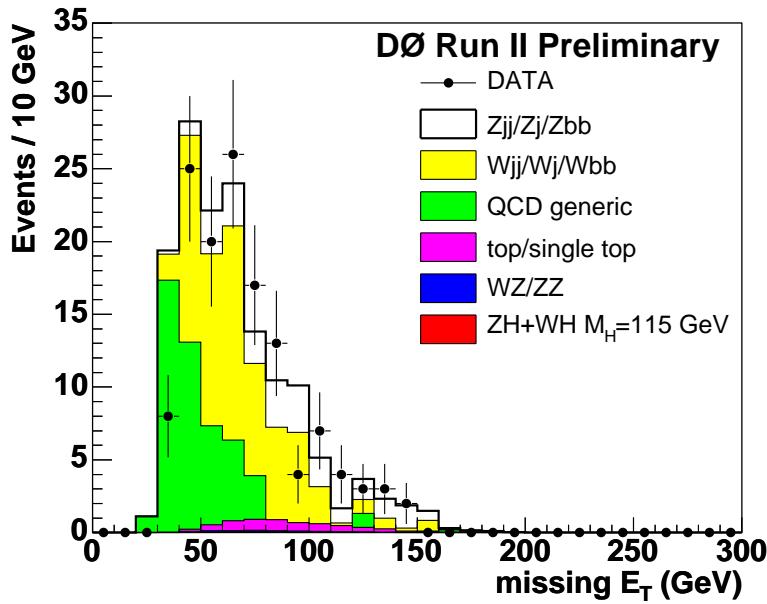
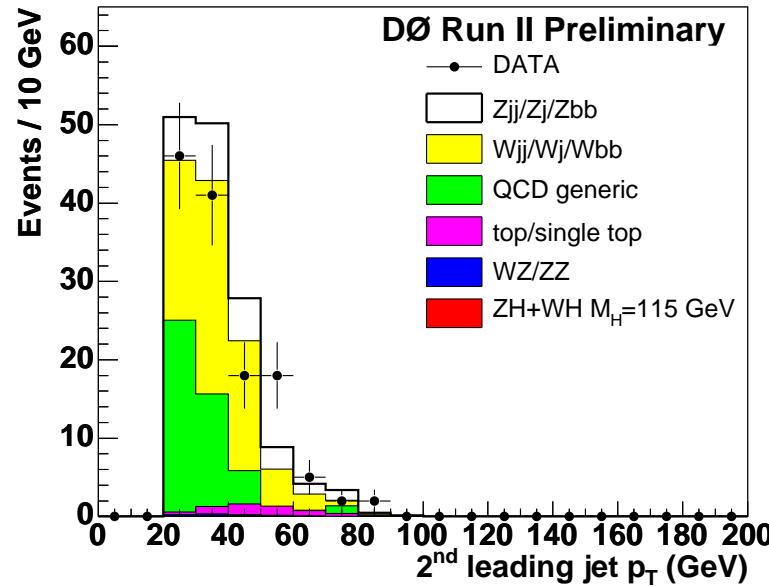
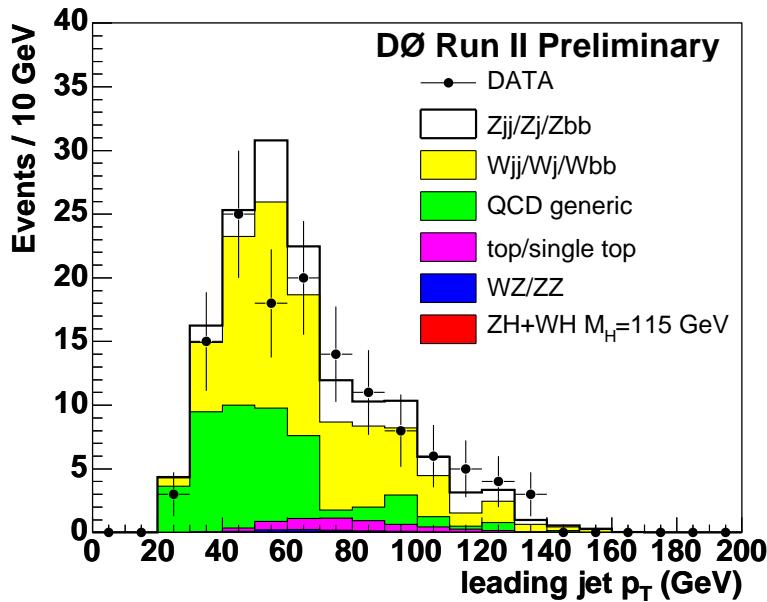


# ZHà vvbb: Distributions before b-tagging



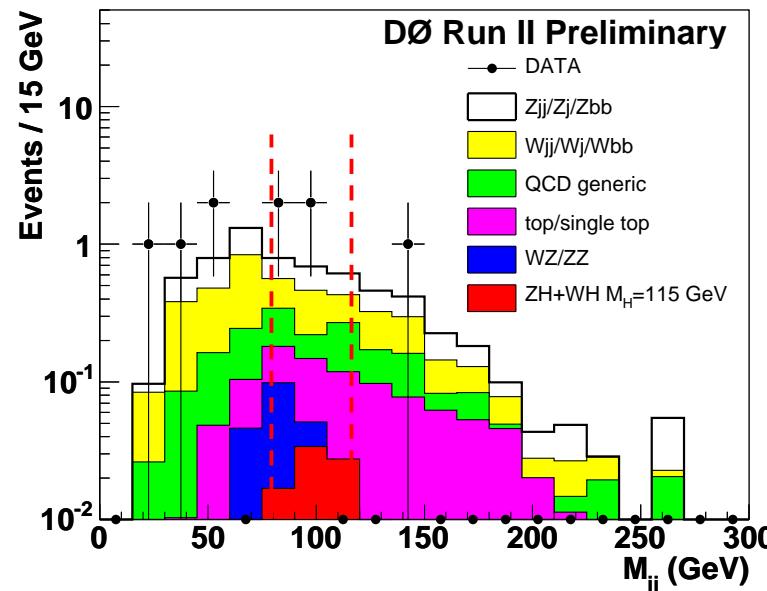
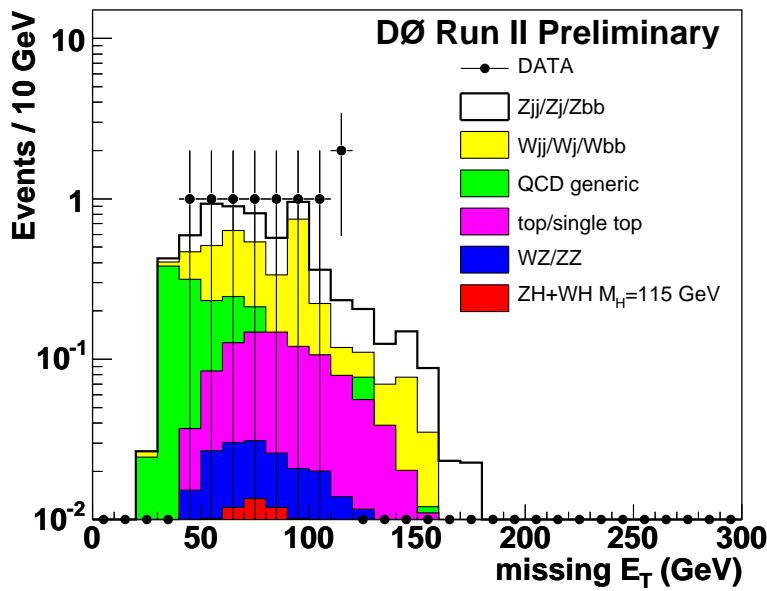
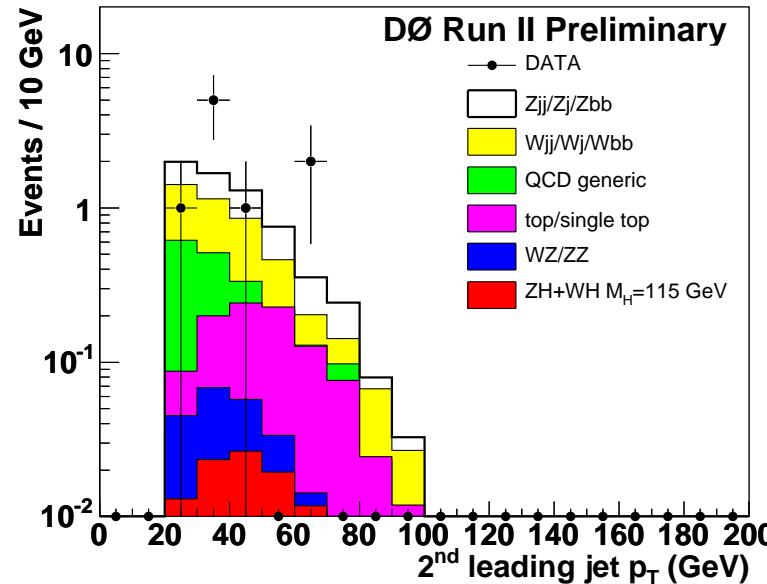
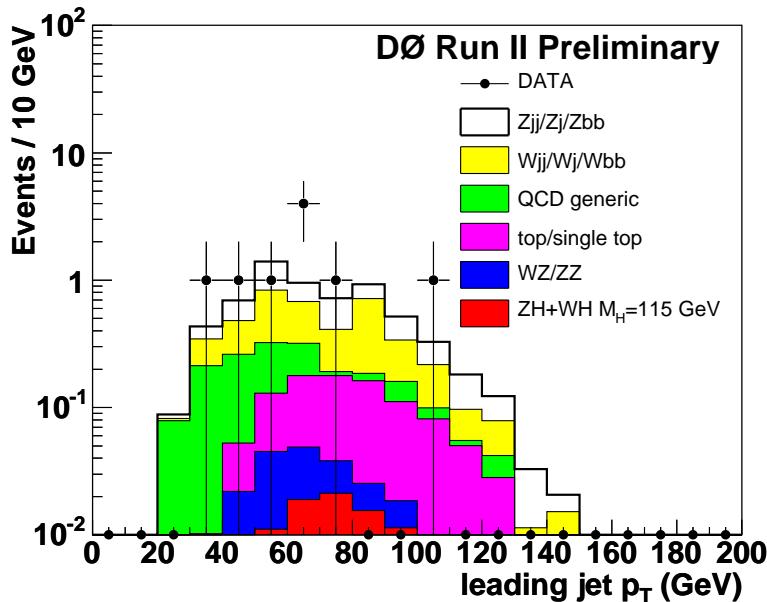
Total  
Data : 2140  
Expect : 2125

# Singly b-tagged events



Total  
Data : 132  
Expect : 145

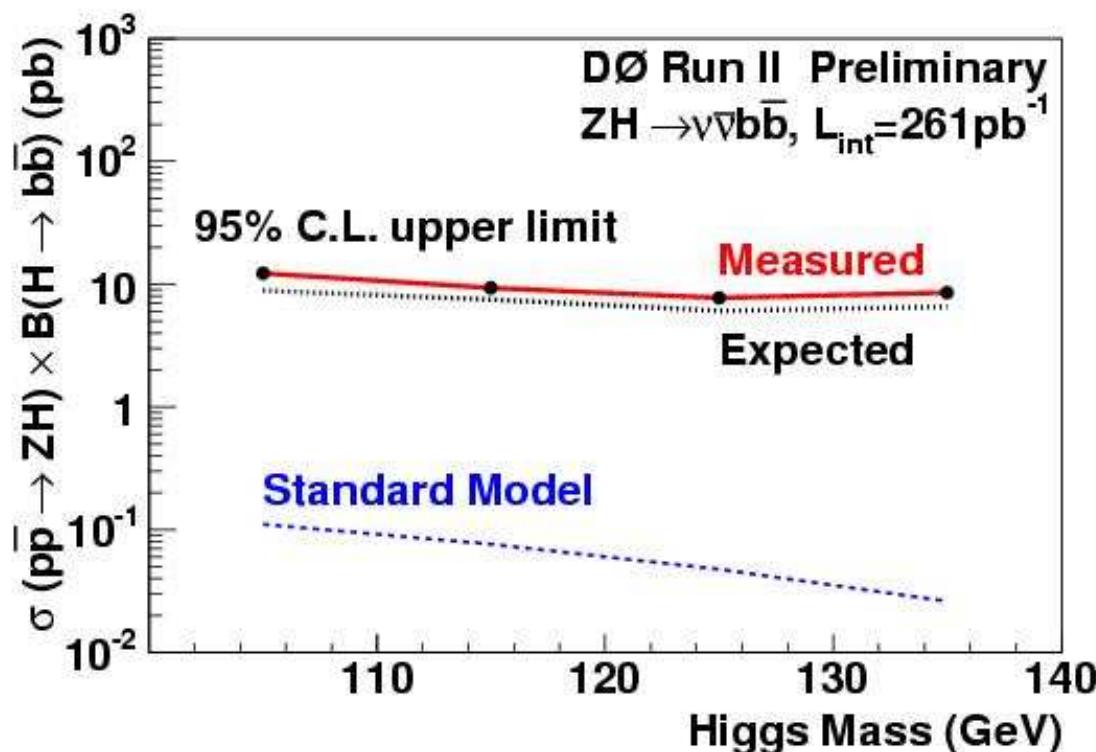
# ZHà vvbb: Doubly b-tagged events



Total  
Data : 9  
Expect : 6.4

# Results (double b-tag)

Mass (GeV)	105	115	125	135	Bkgd. composition (%)
Window	[70,120]	[80,130]	[90,140]	[100,150]	
Data	4	3	2	2	
Acceptance (%)	$0.29 \pm 0.07$	$0.33 \pm 0.08$	$0.35 \pm 0.09$	$0.34 \pm 0.09$	
Total bkgd.	$2.75 \pm 0.88$	$2.19 \pm 0.72$	$1.93 \pm 0.66$	$1.71 \pm 0.57$	
Expected limit (pb)	8.8	7.5	6.0	6.5	
Limit @95% C.L. (pb)	<b>12.2</b>	<b>9.3</b>	<b>7.7</b>	<b>8.5</b>	



## Systematic uncertainty (%)

Source	Sig	bkgd
Jet ID	7	6
JES	7	8
Jet energy resolution	5	3
b-tagging	22	25
Instrumental bkgd.	-	2
Bkgd Cross Section	-	17
<b>Total</b>	<b>26</b>	<b>33</b>

# SUSY Higgs

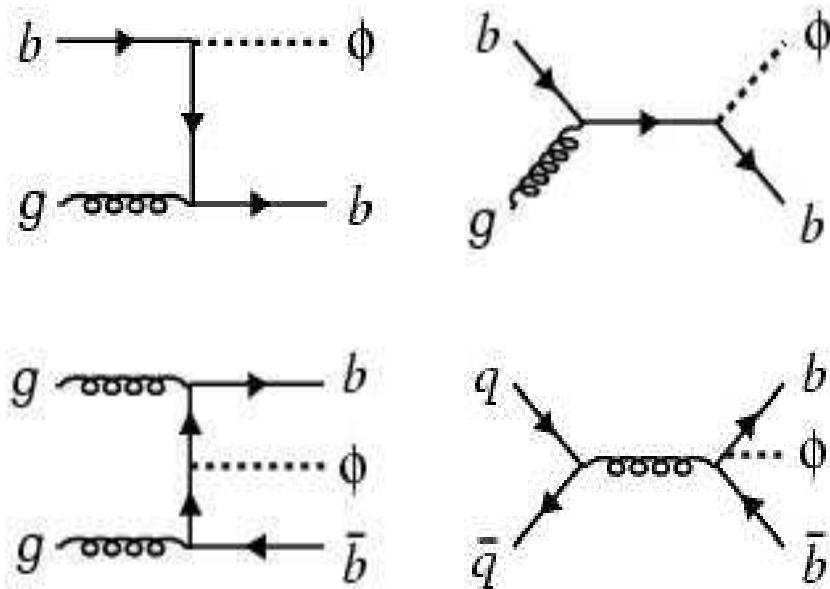
- SUSY Higgs sector consists of **more than one Higgs particle**
- e.g. Minimal Supersymmetric Model (MSSM) :
  - two complex scalar Higgs doublets
  - two VEV's  $v_1$  and  $v_2$  ( $\tan\beta = v_1/v_2$ )
  - 5 Higgs particles :  $h^0$ ,  $H^0$ ,  $A^0$ ,  $H^+$ ,  $H^-$

## In this talk: Search for Neutral Higgses

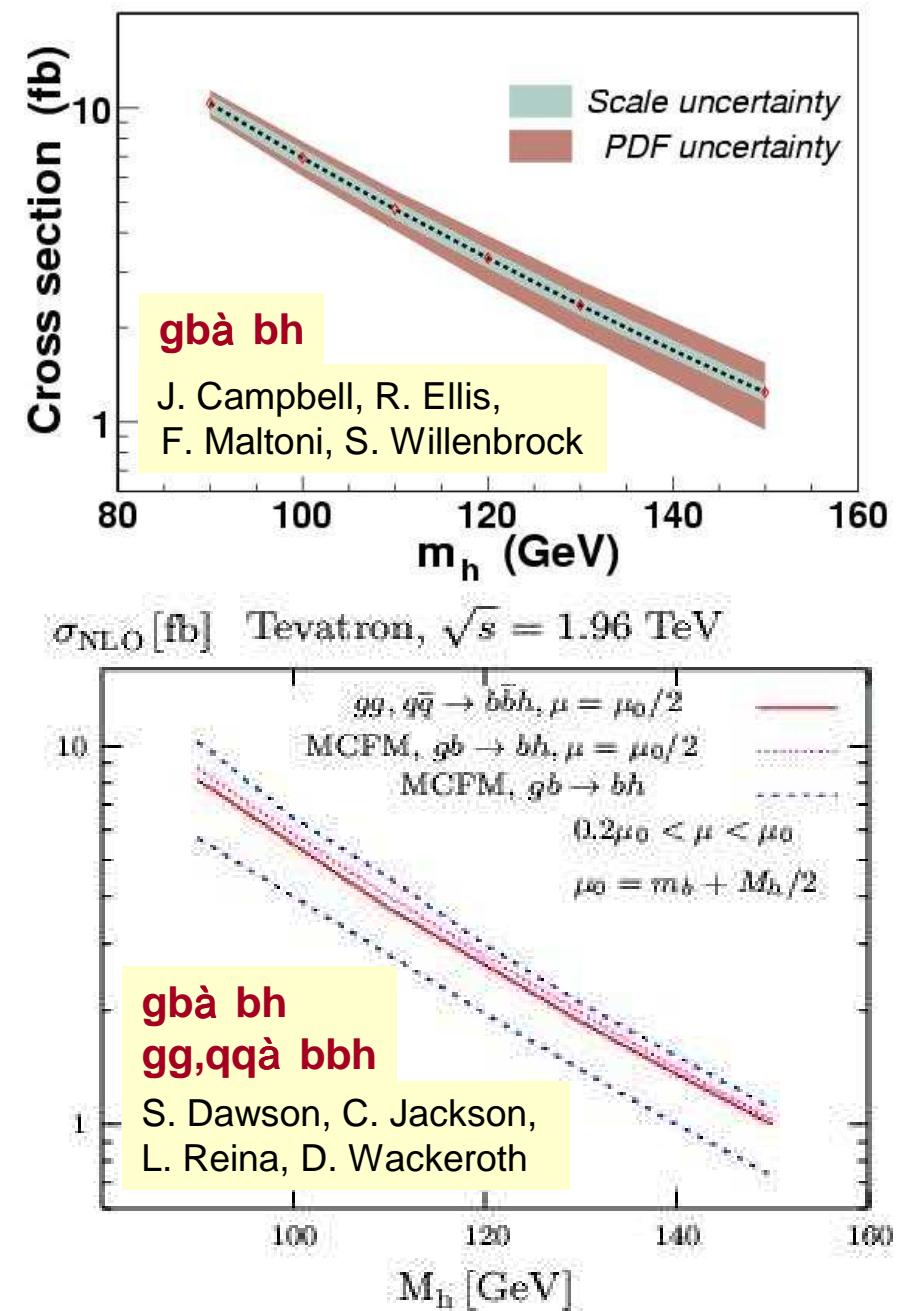
- At large  $\tan\beta$  Higgs coupling to down-type quarks i.e. b-quarks is enhanced with respect to the Standard Model: at tree level  $\sim \tan\beta$   
→ production cross-section rises as  $\tan\beta^2$
- CP-conservation in the Higgs sector is assumed  
→ Mass degeneracy (100-130 GeV:  $h^0, H^0, A^0$  ; higher mass:  $h^0, A^0$  or  $H^0, A^0$ )  
→ Total signal cross-section is assumed to be twice that of the  $A$  boson

# Higgs boson production in association with b quarks

- Two ways to calculate  $b(b)\phi$  processes

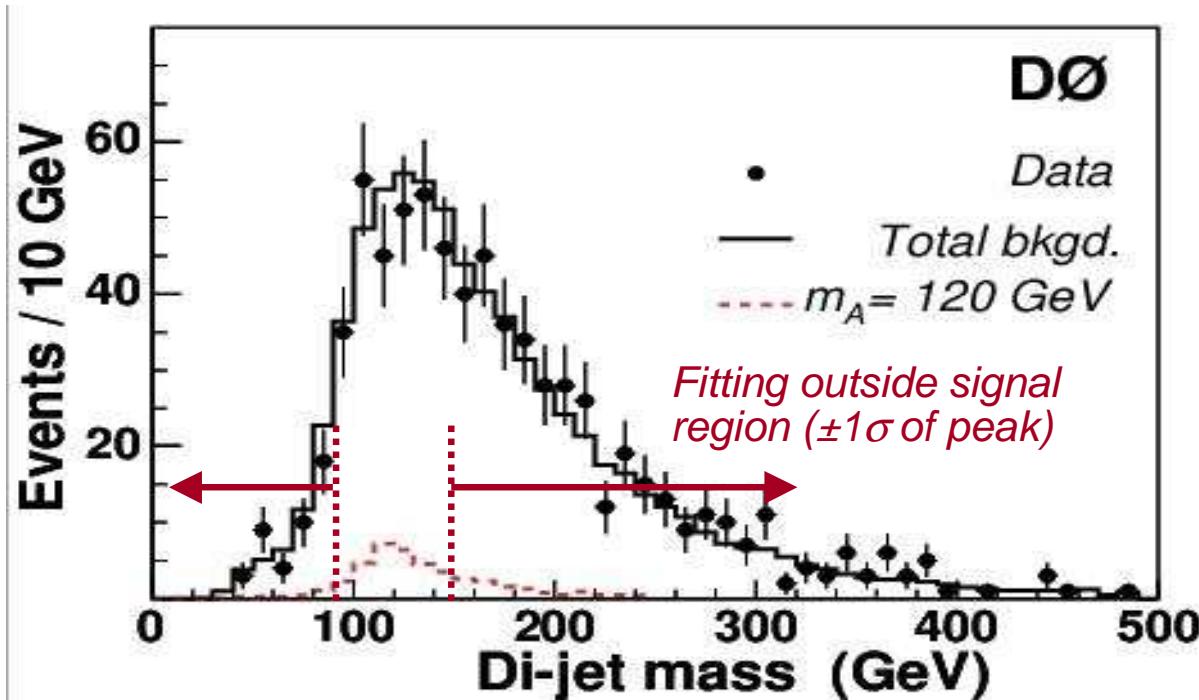


- Both calculations are available at NLO and agree within uncertainties



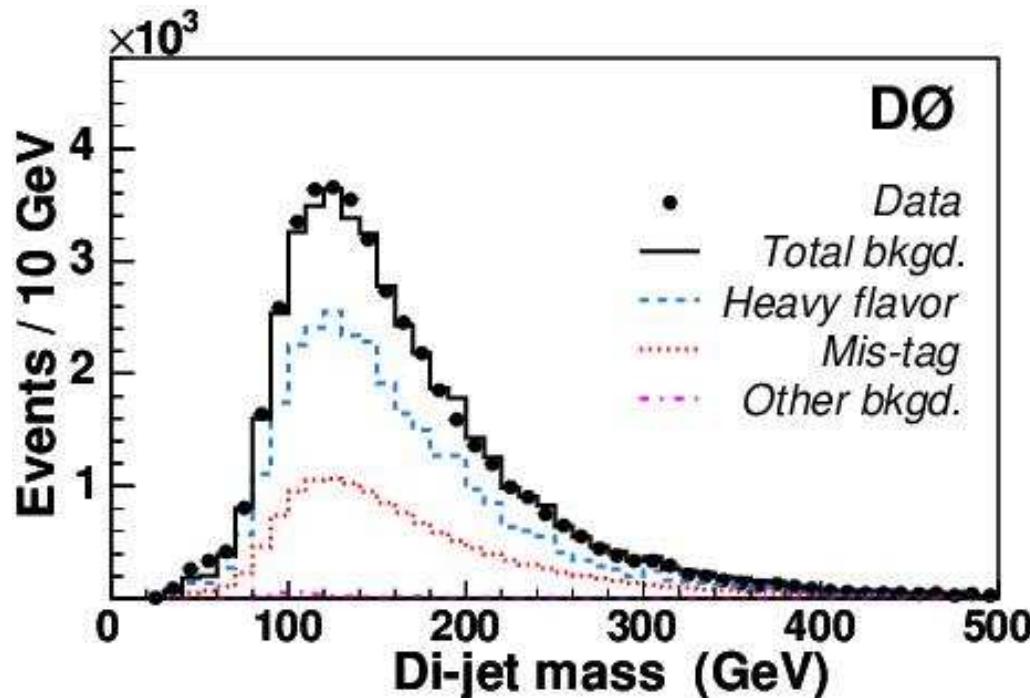
# SUSY Higgs boson search

- Multijet trigger
  - L1: 3 jets of  $> 5$  GeV, L2:  $H_T > 50$  GeV, L3: 3 jets with  $E_T > 15$  GeV
- Offline: at least 3 b-tagged jets
  - $p_T$  and  $\eta$  cuts optimized for Higgs mass and # of required jets
- Look for excess in di-jet mass
- Signal rates and kinematics are normalized to NLO calculations
- Bkgd. shape determined from doubly b-tagged data by applying tag rate function to non-b-tagged jets



## b(b)h:Cross-check of bkgd. method: doubly b-tag sample

- Jet tag rate is estimated from data
- Singly b-tag + TRF di-jet spectrum agrees with doubly b-tag sample



- Additional cross-check is done with ALPGEN MC
- Normalization of MC HF multi-jet processes (mainly bbjj + some bbbb) is left as a free parameter in the fit
  - HF bkgd. agrees within with ALPGEN within ~10%

# Signal acceptance and systematics

- Signal acceptance is  $\sim 0.3\text{--}1\%$  depending on  $m_A$  and final state

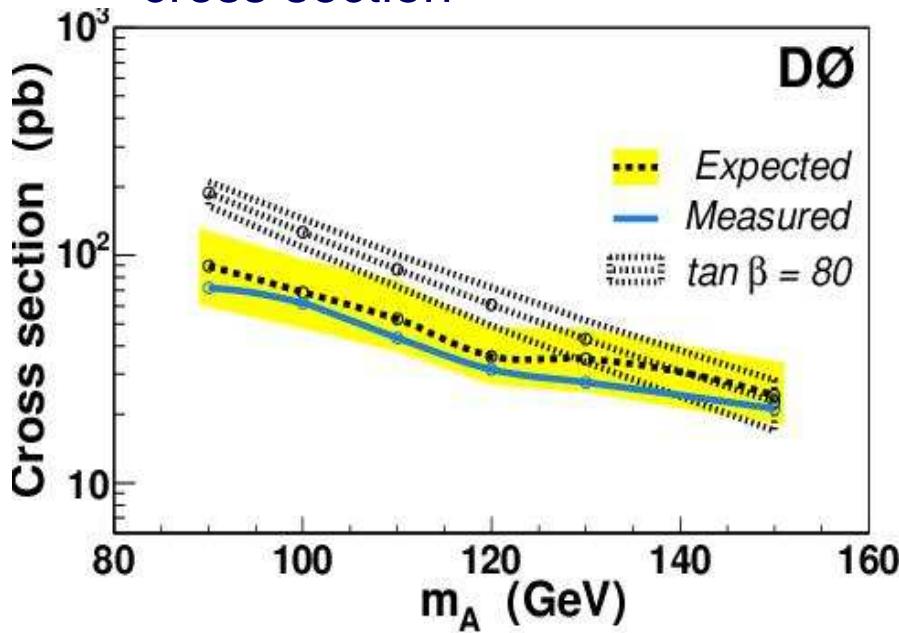
Acceptance breakdown (%)

$m_A$ (GeV)	Trigger	Kinematic	$b$ -tag	Total
90	44	18	3.5	0.3
100	45	24	3.5	0.4
110	56	24	3.9	0.5
120	60	27	4.2	0.7
130	65	29	4.3	0.8
150	76	31	4.4	1.0

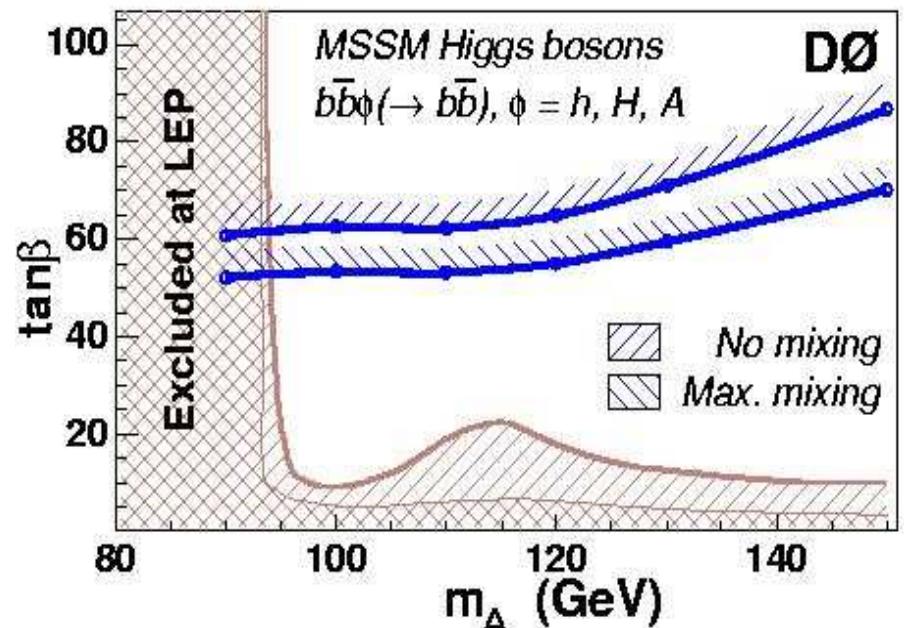
- Systematics on signal efficiency is 21% total:
  - $b$ -tagging (15%), JES/resolution (9%), signal simulation (5%), trigger (9%), luminosity measurement (6.5%)
- Systematic uncertainties for background estimation  $\sim 3\%$

# Results

- Expected and measured 95% C.L. upper limits on the signal cross section



- The 95% C.L. upper limits on  $\tan\beta$  as a function of  $m_A$  and for two scenarios of MSSM

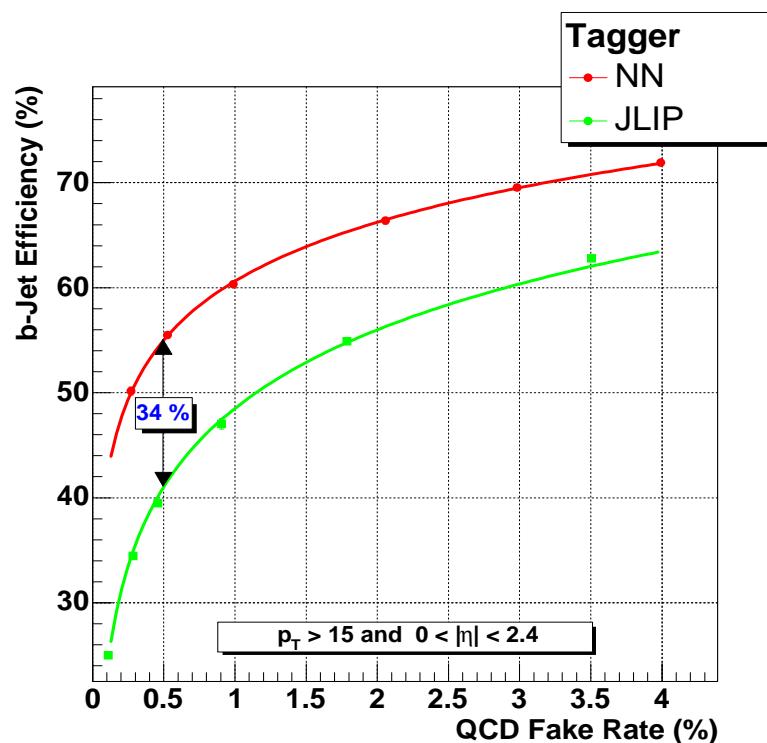


- No mixing in stop sector:  $X_t = 0$   
 $X_t = A_t - \mu \cot\beta$ ,  $A_t$  – tri-linear coupling,  $\mu = -0.2$  TeV
- Maximal mixing:  $X_t = \sqrt{6} \times M_{\text{SUSY}}$ ,  $M_{\text{SUSY}} = 1$  TeV
  - With 5  $\text{fb}^{-1}$  of data, assuming the current performance, can probe  $\tan\beta$  values down to 20-30 depending on the mass, model

# Expected Improvements in b-tagging

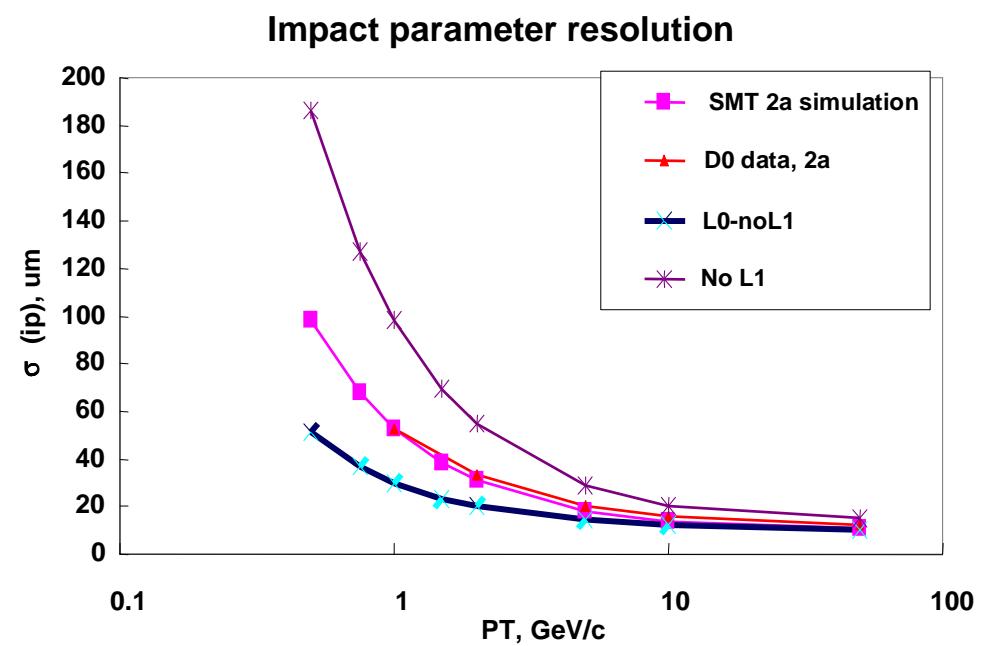
Continue improving  
b-tagging (Neural Net)

the NN tagger combines  
the 3 b-tagging  
algorithms used in DØ



Layer Zero of the Silicon Tracker Upgrade

Layer Zero detector is scheduled to be installed in spring 2006

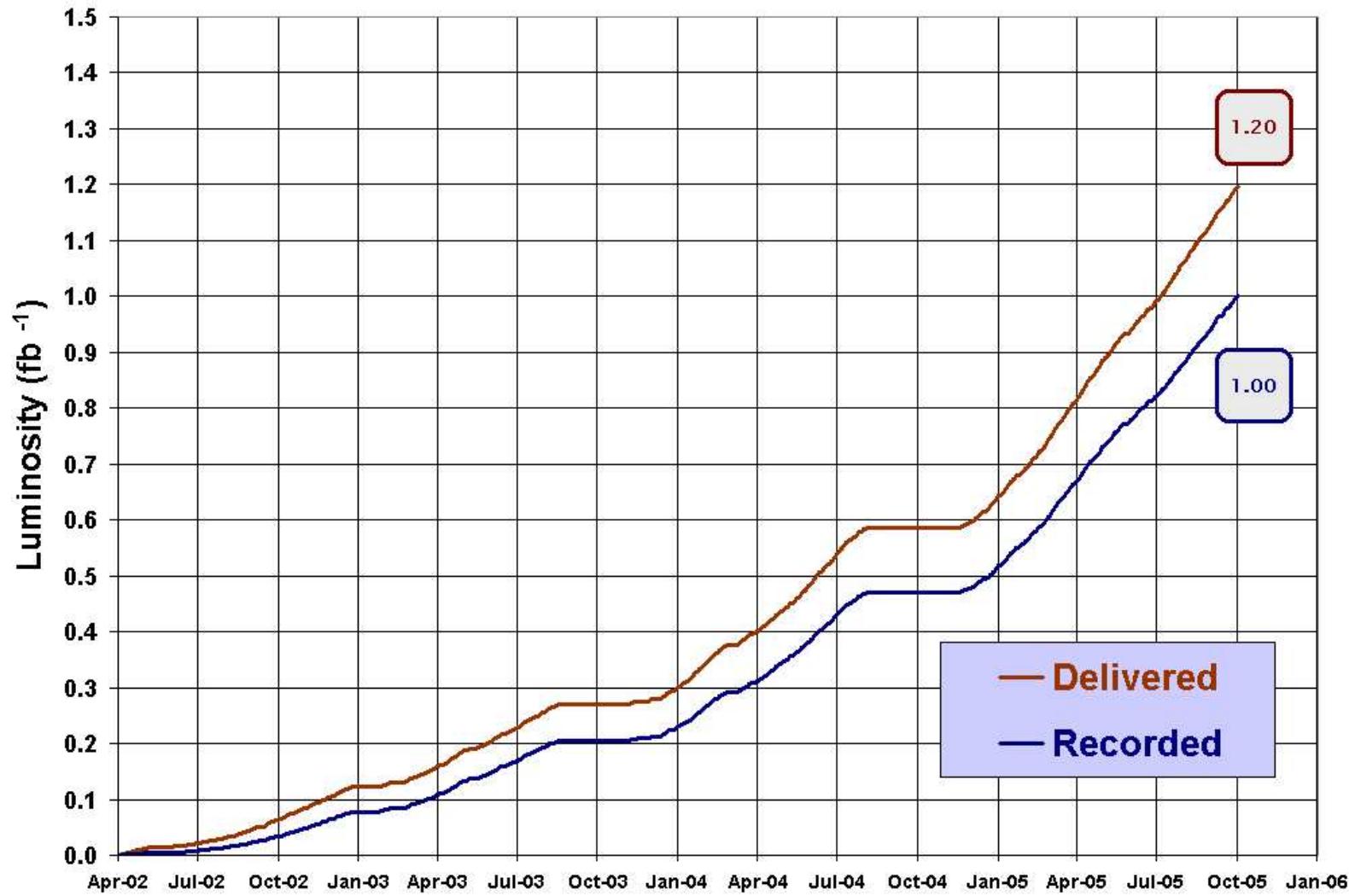


# Tevatron Performance



Run II Integrated Luminosity

19 April 2002 - 20 October 2005



# Summary

- Standard Model and SUSY Higgs searches in multijet events at the Tevatron/DØ Run II have started
- Upgraded accelerator and DØ are performing well, more data are being accumulated ( $1 \text{ fb}^{-1}$  on tape !)
- Work is in progress on improving b-tagging (algorithms, silicon tracker upgrade)
- Stay tuned for new results

# Next Slide is a Backup Slide

# Multi-b-jet background estimation

